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TITLE: MEMS Tribological Reliability

PROPOSING CENTER: Glenn Research Center
PARTICIPATING CENTER: Jet Propulsion Laboratory

PROGRAM GROUP: Electronic Parts Project

PROGRAM OBJECTIVE:
Develop approaches for increased tribological reliability of MEMS devices.

1) Document testing of lubricious/hard coatings on MEMS contacting surfaces for increased device lifetimes.
2) Compare MEMS tribological reliability using alternative substrate materials (e.g. SiC, diamond).
3) Validate tribological performance testing of enhanced MEMS devices under “extreme” conditions.
4) Transfer technology / methodology for enhanced tribological performance back to MEMS foundries.

BACKGROUND:

Micro-electromechanical systems (MEMS) offer tremendous possibilities for volume, mass, and power consumption reductions in spacecraft as well as Earth-bound applications, ranging from simple integrated sensors to micropumps to mechanical fiber-optics switches. In spacecraft, miniaturization offers the potential for new levels of redundancy, allowing for more long term reliability and autonomy [Hermans, 1998]. A key reliability issue for MEMS structures is the friction and wear experienced by moving parts. Even non-rubbing surfaces which simply come in contact can experience adhesion, for example due at this size scale to a powerful water meniscus from adsorbed airborne moisture on hydrophilic surfaces. The majority of MEMS materials now available spring from traditional silicon wafer processing techniques, due to the historical direction from which the MEMS field developed. Unlubricated friction between the resultant silicon dioxide contacting surfaces typically is high, with unacceptably high wear rates for most applications. Conventional liquid lubricants (e.g. oils) dissipate energy excessively at MEMS size scales, proving much too viscous for most MEMS applications.

Multiple approaches to improving MEMS tribological performance are available. Surface coatings can provide both lubrication and hydrophobicity to combat adhesion, and hard coatings may be useable to reduce wear rates. The base material from which the MEMS structures are formed could potentially also be changed, in order to provide native surfaces with better tribological characteristics.

Silicon carbide (SiC) is an enticing semiconductor material, both for its wide band gap (e.g. high temperature / high power density electronics) possibilities as well as its superior mechanical properties as compared to silicon (higher melting point, better radiation damage resistance). Recent advances in as-grown doping levels of epitaxial SiC expand the potential electronics applications of SiC [Larkin et al., 1994]. Initial tests of some SiC MEMS-type films demonstrated lower erosion rates than in treated and untreated silicon single crystal and polycrystalline specimens [Bhushan et al., 1998]. SiC can also be induced to produce graphite, a common solid lubricant, on its surface [Wheeler and Pepper, 1987].

Recently created, the Glennan Microsystems Initiative represents a collaboration between NASA, Case Western Reserve University, and Ohio businesses to expand the application of MEMS. With joint funding from NASA and the State of Ohio, the effort will address the need for microsystems that can withstand harsh conditions, and is a good potential source for co-funding, given involvement by local businesses. There is an opportunity here to focus attention during the early stages of SiC MEMS development on the tribological / reliability challenges ahead.

DESCRIPTION and APPROACH:

We propose to measure the lifetime tribological advantages of diamond-like-carbon (DLC), diamond, cubic boron nitride (c-BN), carbon nitride(CN), and aluminum nitride (AlN) contacting surfaces in MEMS-type applications, both on traditional silicon-based as well as on SiC-based MEMS test structures. Existing tribological test facilities will be used with ultrahigh vacuum or controlled atmosphere, cryogenic or heated specimen mount, and in-situ scanning Auger surface analysis capabilities. Well characterized MEMS test structures from the MEMS Reliability Alliance through JPL will provide the design foundation for tribological testing.

More specifically, we propose to:

1) Quantitatively evaluate the lifetime tribological benefits of DLC, diamond, c-BN, CN, and AlN films on traditional MEMS devices as a function of production conditions, device class, and service environment.
2) Iteratively communicate testing results to component suppliers.
3) Evaluate comparative tribological performance of SiC-based test structures versus silicon-based, with and without coatings.
4) Establish testing methods for advanced tribological coatings on SiC-based MEMS structures.
5) Initiate comparison with MEMS components derived from thick-film, free-standing diamond substrates.

BENEFITS:

This proposal connects GRC-based tribological and surface characterization expertise with the JPL-based MEMS Reliability Alliance, benefiting both. Additional resources are represented by the NASA-cosponsored Glennan Microsystems Initiative contributing in related MEMS research areas, which will also benefit from the MEMS reliability information generated through this proposal.

DELIVERABLES:

1) MEMS test structures for DLC / diamond / c-BN / CN / or AlN tribocoatings, as appropriate. /JPL
2) MEMS tribological reliability data – from ambient to extreme (e.g. “mission”) conditions. /GRC
3) Testing for SiC MEMS of DLC / diamond / c-BN / CN / or AlN coatings. /GRC
4) Publication of MEMS tribological testing results. /GRC
5) Initial technology selection comparison of potential diamond substrate MEMS structures. /GRC

SCHEDULE:

Task	Completion
First MEMS test structures sent from JPL to GRC (on-going)	Q1/FY00
Initial characterization and first coatings of MEMS test structures (on-going)	Q2/FY00
Initial tribological testing of polycrystalline SiC for MEMS test structures	Q2/FY00
Initial tribological testing of polycrystalline diamond MEMS test structures	Q3/FY00
Publication of to-date tribological reliability improvement testing and methods	Q4/FY00
Characterization / testing results feedback to collaboration partners	continuous

Publication of final reliability improvement testing and methods guide
Q4/FY02

PARTNERSHIPS:

The primary partnership established through this proposal is between the JPL-led MEMS Reliability Alliance (Russell Lawton) and the Tribology and Surface Science Branch at GRC (P. Abel and K. Miyoshi), potentially enabling a speedier introduction of MEMS technology into both weight-saving spacecraft applications as well as harsh terrestrial environments. The Glennan Microsystems Initiative (W. Merrill) as a potential participant both benefits from this work, and represents possible additional funding for related research areas. Research 2000 Inc. (W. Mueller) has demonstrated capability to produce diamond MEMS structures, and K Systems Inc. has on-going interest in the various hard coatings.

PRINCIPAL INVESTIGATORS:

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